Fermi National Accelerator Laboratory

Isolated Single and Double Direct Photon Production at CDF

The CDF Collaboration

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ABSTRACT

We present measurements of isolated direct photon production in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV from the 1988-89 run of the Collider Detector at Fermilab (CDF). Quantum Chromodynamics is tested against measurements of the transverse momentum spectrum of single photon production ($\bar{p}p \rightarrow \gamma + X$), double photon production ($\bar{p}p \rightarrow \gamma\gamma + X$), and the distribution of $\cos\theta^*$ in photon-jet events ($\bar{p}p \rightarrow \gamma J + X$). We also present a measurement of the *isolated* production ratio of η and π^0 mesons $(\bar{p}p \rightarrow \eta + X)/(\bar{p}p \rightarrow \pi^0 + X) = 1.02 \pm .15(stat) \pm .23(sys)$.

1. Introduction

Measurements of prompt photons in $\bar{p}p$ collisions is a test of Quantum Chromodynamics (QCD) and a constraint on parton distributions. Here we probe a previously unexplored range of fractional momentum ($.015 < X < .075$) where gluons are the dominant parton.

2. Background Subtraction Methods

In CDF[1] we define a photon[2] as one or two towers of energy in the electromagnetic calorimeter (CEM), with less than 11% hadronic energy and no charged track. Jet backgrounds were reduced by requiring the photon to be *isolated*: the extra energy inside a cone of radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.7$ around the photon is less than 15% of the photon energy. The remaining background is dominated by isolated single π^0 and η mesons. Two background subtraction methods were used: the *profile method* uses a χ^2 test of the transverse profile of the photon measured in strip chambers (CES) embedded at shower maximum in the CEM, and the *conversion method* counts the number of conversion pairs in the central drift tubes (CDT). The profile methods efficiency, for photons and background, has been simulated with testbeam electrons and checked against electrons from W decay, photons from η decay, and π^0s from ρ

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* The collaborating institutions are listed in appendix A.
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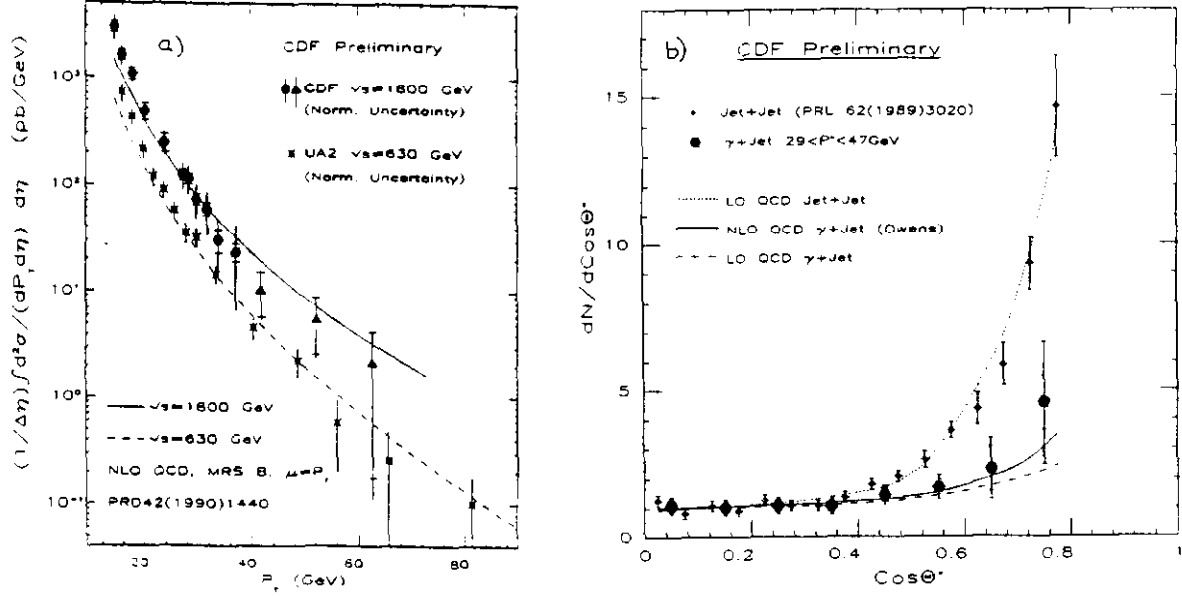
Figure 1: a) The isolated prompt photon cross section is compared to QCD. b) The CMS angular distribution for photon+jet and jet+jet events is compared to QCD.

decay. The conversion methods efficiency is P_t independent; it has been measured from photons and π^0s, and agrees with the amount of material in the detector. The two methods give the same cross section in their common region of P_t.

3. Isolated Single Photon Cross Section

The isolated photon cross section from CDF and UA2[3] is shown in Fig. 1a compared to QCD calculations[4] at next to leading order (except photon bremsstrahlung is only included at leading order). The inner error bars are the statistical error and the outer error bars are the statistical and P_t dependent systematic uncertainty combined in quadrature. The P_t independent component of the systematic uncertainty is shown as the normalization uncertainty. The QCD prediction changes within 30% when the structure functions are varied among commonly used sets, and changes by about 10% when the renormalization scale is halved or doubled. The data and theory are only in qualitative agreement; including bremsstrahlung at next-to-leading order may improve the comparison and allow a measurement of the gluon distribution from these data.

4. Photon + Jet CMS Angular Distribution

Photon events contain jets; in the lowest order picture there is a single jet azimuthally opposite the photon. For this analysis we define the jet axis to be the momentum weighted vector sum of the axes of the three highest P_t CDF jets[5] with $P_t > 10$ GeV and azimuthal separation from the photon $\Delta\phi_{\gamma j} > 120°$. The three lab frame variables are the photon's P_t and pseudorapidity, η_γ, and the jet's pseudorapidity, η_{jet}. The jet's P_t is not used. The three CMS variables are

$$\eta^* = (\eta_\gamma - \eta_{jet})/2, \quad \eta_{boost} = (\eta_\gamma + \eta_{jet})/2, \quad P^* = P_t \cosh\eta^* \tag{1}$$
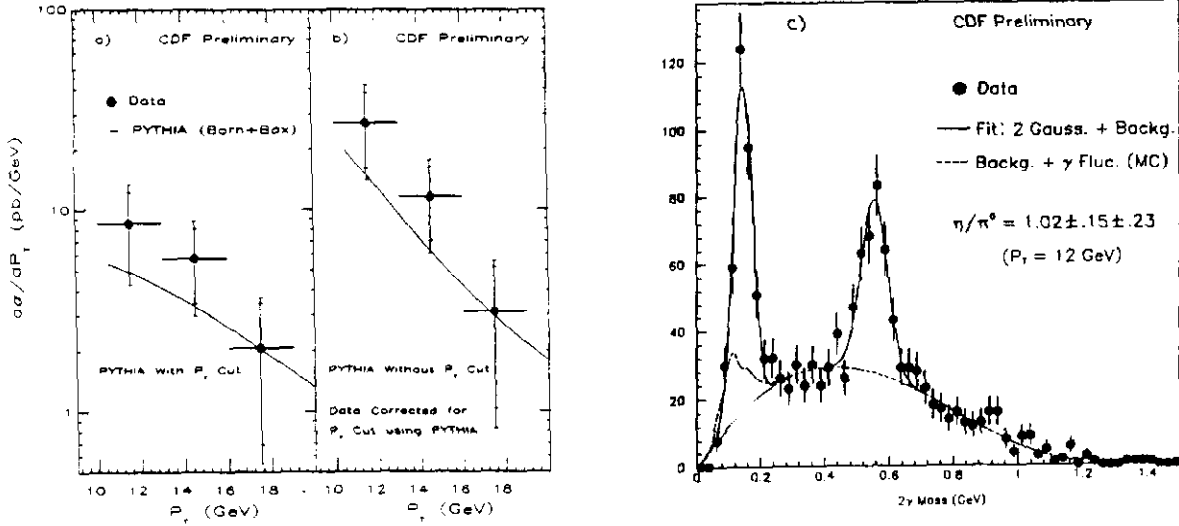
Figure 2: a) The isolated double direct photon cross section compared to PYTHIA with a P_t cut on each photon. b) Same without a P_t cut on each photon (Data corrected with PYTHIA). c) The invariant mass of two indirect photons (NOT the di-photon mass) shows peaks from isolated π^0 and η mesons.

and the cosine of the CMS angle is $\cos\theta^* = \tanh\eta^*$. For $23 < P_T < 45$ GeV, we form two regions that have uniform acceptance in the CMS variables: Region 1 is $(0.0 < \eta^* < \pm0.7, \mp0.2 < \eta_{boost} < \pm0.9, 29 < P^* < 45$ GeV) and Region 2 is $(\pm0.3 < \eta^* < \pm1.1, \mp.2 < \eta_{boost} < \mp1.2, 38 < P^* < 47$ GeV). The two regions are normalized to each other using the overlap in $\cos\theta^*$. In Fig. 1b the photon+jet $\cos\theta^*$ distribution is compared to leading order and next-to-leading order calculations[6]; QCD predicts a fairly flat distribution resulting from subprocesses with t-channel quark exchange (spin 1/2). Also in Fig. 1b we show the $\cos\theta^*$ distribution for jet+jet events[7] compared to leading order calculations; QCD predicts a Rutherford-like scattering distribution resulting from subprocesses with t-channel gluon exchange (spin 1).

5. Isolated Double Photon Cross Section

The three types of subprocesses which contribute to the cross section for directly producing two photons (di-photons) are the *Born* diagram ($qq \to \gamma\gamma$), the *box* diagram ($gg \to \gamma\gamma$), and diagrams with photon *bremsstrahlung*. CDF triggers on these events by requiring two clusters of electromagnetic energy, each with at least 10 GeV P_t. Cuts similar to those for single photons are employed, however, the isolation cut on each photon requires that the sum of the neighboring towers is less than 10% of the photon energy. For photons with $10 < P_t < 35$ GeV, there are 149 diphoton candidates (298 photons). The backgrounds from isolated $\gamma\pi^0$ and $\pi^0\pi^0$ events are subtracted using the *profile* method. Roughly one third of the sample are true di-photons (40% if we restrict ourselves to photons with $10 < P_t < 19$ GeV). In Fig. 2a we show the di-photon

cross section as a function of the P_t of each photon; each event has two entries with 0.5 weight. This is compared with a monte carlo calculation, including only the Born diagram and the box diagram (no bremsstrahlung diagrams). The requirement that each photon have $10 < P_t < 35$ GeV, in the presence of a P_t kick from QCD radiation, makes the slope of the prediction decrease at lower P_t. In Fig. 2b we remove the P_t requirement in the monte carlo, which then gives a typical falling spectrum, and scale the data by the ratio of the calculations in Fig. 2b and 2a. In either plot the data is in qualitative agreement with the incomplete calculations.

6. Isolated Meson Production Ratio η/π^0

Isolated η and π^0 mesons are the primary background to direct photons, so their relative production rates is of some interest. Also, the isolation requirement, described in section 2, may enhance the fraction of directly produced mesons[6] relative to mesons from jet fragmentation. We use small CES clusters (25 mrad), to separate the closely spaced photons from π^0s as well as ηs, and require the two highest energy CES clusters to be in the adjoining CEM towers of a single isolated EM cluster. Multi-π^0 backgrounds are reduced by requiring the energy sum of extra CES clusters in the EM cluster be less than 30% of the sum of the highest two. Misidentification of single photon showers as a π^0 at the tower boundary, is reduced by requiring the two towers energy asymmetry $(|E_1 - E_2|/(E_1 + E_2))$ to be less than 0.8. In Fig. 2c the two photon mass distribution shows the π^0 and η peaks; this is fit with two gaussians and a polynomial-like background $(\chi^2/DOF = .95)$. Also shown is the estimated amount of single photons misidentified as π^0s. Subtracting the backgrounds, and using the relative acceptances of π^0s and ηs from a full trigger and detector simulation, we obtain a production ratio $\eta/\pi^0 = 1.02 \pm .15(stat) \pm .23(sys)$. The CDF measurement, for isolated mesons with mean P_t of 12 GeV, is within 1.3σ of the UA2 measurement[9] of $0.60 \pm .04 \pm .15$ for non-isolated mesons with mean P_t of 4.5 GeV.

Appendix A: CDF Collaborating Institutions

ANL - Brandeis - University of Chicago - Fermilab - INFN, Frascati - Harvard - University of Illinois - KEK - LBL - University of Pennsylvania - INFN, University of Scuola Normale Superiore of Pisa - Purdue - Rockefeller - Rutgers - Texas A&M - Tskuba - Tufts - University of Wisconsin

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